Serious seatbelt injuries sustained by pregnant women sitting in rear seats: anthropometric analyses and confirmation in sled tests

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Abstract The objective of this study was to examine seatbelt–neck contact in pregnant women seated in the rear seat of a motor vehicle and to measure neck compression in these women during frontal vehicle collision sled tests. Late-term pregnant Japanese volunteers sat in the left side of the rear seat of a typical mid-size passenger sedan with their seatbelt fastened. The quantitative characteristics of their seated posture and seatbelt paths were measured. Next, sled tests were performed using a pregnant body dummy to simulate a full-frontal rigid barrier impact at target velocities of 29 km/h and 48 km/h. The shoulder belt deviated to the right side and subsequently contacted the neck of the shorter women (mean height, 152.3 ± 3.0 cm). During the sled tests, the shoulder belt compressed and applied more than 12.8 MPa of pressure to the neck. Complex head movements consisting of flexion, lateral deviation, and clockwise rotation around the x-axis were also observed.

The results of this study demonstrate that the shoulder belt of the seatbelt contacts the neck of shorter late-term pregnant women and causes neck compression during frontal collisions. New rear seatbelt systems are needed to enhance passenger safety, particularly the safety of pregnant women.

Keywords Injury, Pregnant woman, Rear seat, Seatbelt, Frontal collision

I. INTRODUCTION

Motor vehicle collisions (MVCs) are a leading cause of death globally, resulting in 1.2 million deaths every year worldwide [1]. They are also the largest cause of accidental death and disability among pregnant women [2]. A recent study in Japan involving pregnant women at 35–37 weeks gestation found that 2.9% had experienced an MVC as a vehicle occupant during their current pregnancy [3]. The seatbelt is widely recognised as an effective safety tool, and as such its use is legally required in many developed countries. Because seatbelt use reduces the risk of fatal injuries for pregnant women and their fetuses in impact scenarios [4-6], it is a legal requirement in Japan for all pregnant drivers and passengers. However, in spite of this legal requirement, some pregnant women sitting in the rear seat tend not to fasten their seatbelt because of the discomfort caused by seatbelt contact with their neck. In addition to comfort issues, if the belt were to make contact with the neck of a rear-seat passenger it could lead to adverse outcomes during a collision. Therefore, it is necessary to develop a seatbelt that is both comfortable to use for pregnant women and effective in an impact scenario.

Specifically, the objective of this study was to determine the extent of seatbelt-neck contact in pregnant women seated in the rear seat of a motor vehicle and to measure the neck compression and head and neck kinematics of pregnant women during a frontal MVC.

II. METHODS

Measurement of the belt paths of pregnant women

Because the anthropometric changes of pregnancy are most pronounced during late pregnancy and the pregnant crash-test dummy is designed to simulate a woman at 30 weeks of gestation, we considered that late term pregnant women were most appropriate for our analysis. After an open call for volunteers, 12 pregnant women of ≥30 weeks gestation (mean 33.9±3.3 weeks pregnant) were chosen as participants. Written informed consent was obtained from all participants, and this study was approved by the Ethics Committee of the Dokkyo Medical University School of Medicine. After the participants had seated themselves on the left side of the rear

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seat of a typical mid-size passenger sedan and put their own seatbelt on, we observed the seatbelt path. In these pregnant women, the sternum and umbilicus were easy to find and were useful landmarks for determining belt path. The following parameters were measured: (1) the distance from the top of the sternum to the centre of the shoulder belt (cm); (2) the distance from the centre of the shoulder belt to the umbilicus (cm); and (3) the distance from the umbilicus to the centre of the lap belt (cm). A Mann-Whitney test was used to assess the significance of differences in these values between women whose seatbelt contacted their neck and those whose seatbelt did not contact their neck. Differences with a p value of less than 0.05 were considered statistically significant.

Sled test with a pregnant body dummy

The dummy used in the sled tests was the latest version of the Maternal Anthropometric Measurement Apparatus, version 2B (MAMA-2B), which is based on the Hybrid-III American female 5th %ile dummy (AF05). The pelvis, sternum and ribcage were modified to accommodate a silicon rubber bladder, representing the uterus at 30 weeks' gestation. The seat supplied represented the right side of the rear seat of a typical mid-size passenger sedan, with a seatback angle of 20◦. The seatbelt was applied to the dummy without a pre-tensioner or force-limiter. Sled tests were performed at the HYGE sled test facility in accordance with previously published protocols [3]. Two test conditions were set, these consisted of full frontal impact at a target velocity of 29 km/h and 48 km/h. Acceleration pulses (crash pulses) in each condition were applied as previously reported. During the test, we measured the head and chest acceleration in each direction, the neck acceleration and moment, and displacement of the chest and head.

Pressure on the neck was measured using PRESCALE (Fuji Film, Tokyo, Japan) during the sled test. PRESCALE is a film that measures pressure and pressure distribution. Areas where pressure is applied become red in response to the pressure, and the magnitude of pressure is shown by changes in the colour density. The films were attached to the front right side of the neck, where the shoulder belt may make contact.

III. RESULTS

1. Belt path of the pregnant women

Anthropometric data (means ± standard deviations) for the pregnant women were: age, 32.5 ± 2.3 years (range, 30–38 years); height, 156.8 ± 4.5 cm (range, 148–165 cm); weight, 61.9 ± 14.0 kg (range, 42.0–77.6 kg). In four pregnant women (Contact group), the shoulder belt deviated towards the right side and subsequently made contact with the neck. In the remaining eight pregnant women, the shoulder belt stayed in the correct position and did not make contact with the neck (Non-contact group). When anthropometric characteristics were compared between these two groups, the women in the Contact group was significantly shorter than those in the Non-contact group (152.3 ± 3.0 vs. 159.0 ± 3.3 cm, p=0.008, Fig. 1). However, there were no significant differences in age, weeks pregnant, or weight, between the Contact and Non-contact groups (33.0 ± 2.2 vs. 32.0 ± 2.4 years; 33.5 ± 3.1 vs. 34.1 ± 3.6 weeks; 61.0 ± 22.3 vs. 62.4 ± 9.6 kg, respectively; p>0.05).

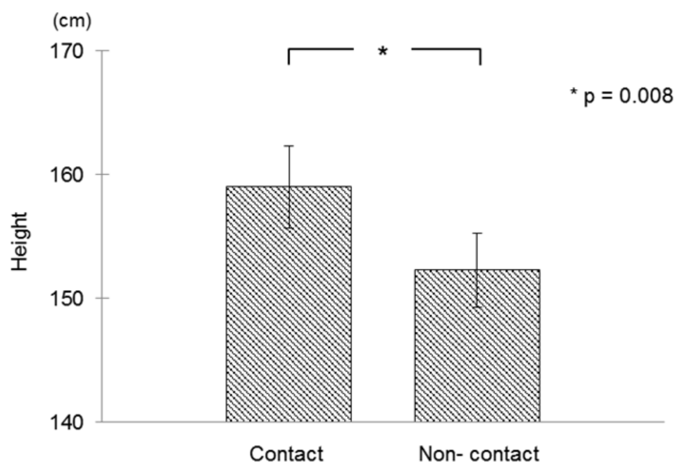


Fig. 1. Comparison of the height of the pregnant women in the Contact and Non-contact groups (statistically significant, p=0.008).

In all participants, the overall mean distances from the top of the sternum to the centre of the shoulder belt, from the centre of the shoulder belt to the umbilicus, and from the umbilicus to the centre of the lap belt were 6.6 ± 3.0 cm, 27.0 ± 4.2 cm, and 9.2 ± 2.0 cm, respectively. When these values were compared between the Contact and Non-contact groups, the distance from the top of the sternum to the centre of the shoulder belt was significantly shorter in the Contact group (3.9 ± 3.5 cm) than it was in the Non-contact group (8.0 ± 1.6 cm; p=0.03). However, the differences in the other two measurements were not statistically significant (28.7 ± 6.7 vs. 26.0 ± 1.8 cm and 8.7 ± 3.0 vs. 9.4 ± 1.6 cm for the distance from the shoulder belt to the umbilicus and from the umbilicus to the centre of the lap belt, respectively; p>0.05).

2. Sled test

Before the tests, the seatbelt path on the dummy was observed. The dummy was based on the Hybrid-III AF05 version and was similar in height to the Contact group (152.3 ± 3.0 cm); as expected, the shoulder belt made contact with the neck of the dummy. The shoulder belt was positioned on the left side and was placed so that it avoided the protruding abdomen (Fig. 2). The distance between the chin and the centre of the shoulder belt was 111.0 cm.

Fig. 2. Belted pregnant body dummy, MAMA-2B, used in the sled tests.

1) Overall kinematics of the dummy

Figure 3 shows the changes in chest accelerations after impacts at each velocity. During the low velocity impact, 73.1 ms after impact initiation (onset of sled pulse) the dummy moved 118.0 mm forward of its initial positon. During the high velocity impact, 65.4 ms after impact initiation the dummy moved 164.1 mm forward of its initial position.

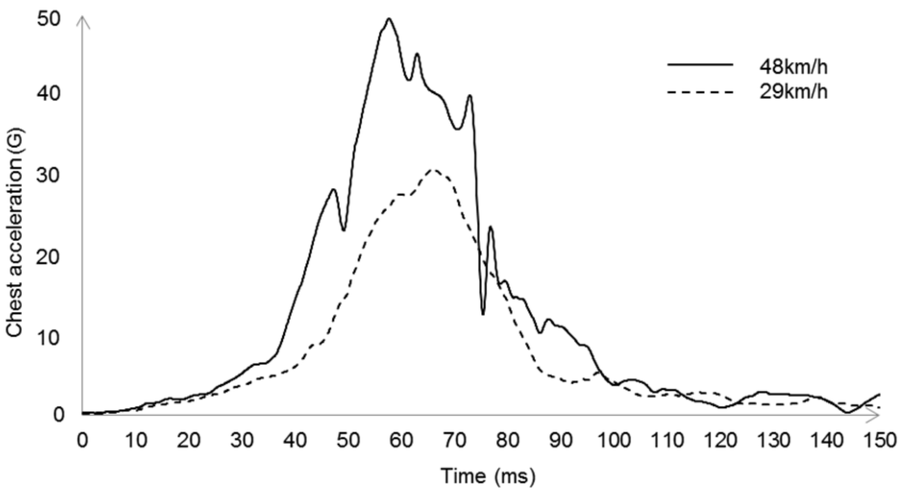


Fig. 3. Time course of chest acceleration at each impact velocity.

2) Movement of the head

Accelerations of the head in each direction over time are shown in Fig. 4 (low velocity) and Fig. 5 (high velocity). As the neck flexed after the impact, maximum acceleration in the X direction was 201.6 m/s^2 at 101.1 ms after low velocity impact initiation and 339.4 m/s^2 at 100.8 ms after high velocity impact initiation. In the Y direction (positive values indicate movement from right to left), maximum accelerations of 27.5 m/s^2 and 37.6 m/s^2 were attained at 69.9 ms and 61.9 ms after initiation of the low and high velocity impacts, respectively. A kinematic sequence showing the changes in dummy position that occurred during high velocity impact is provided in Fig. 6.

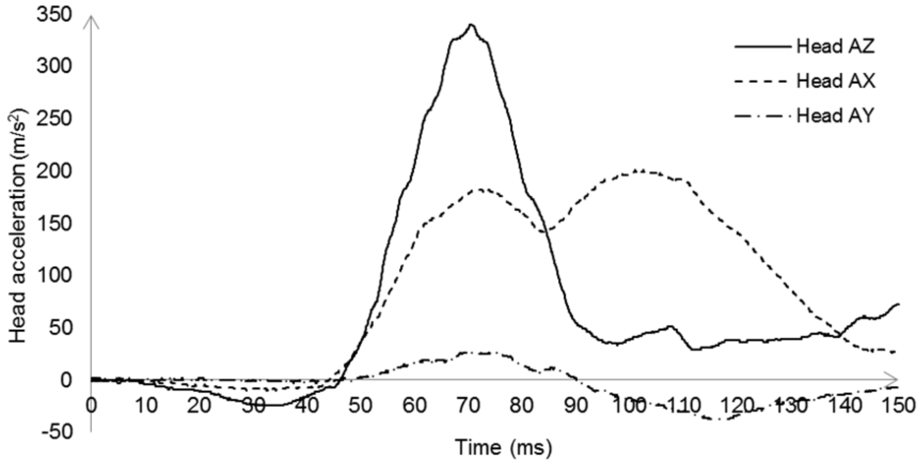


Fig. 4. Time course of head acceleration in each direction at an impact speed of 29 km/h.

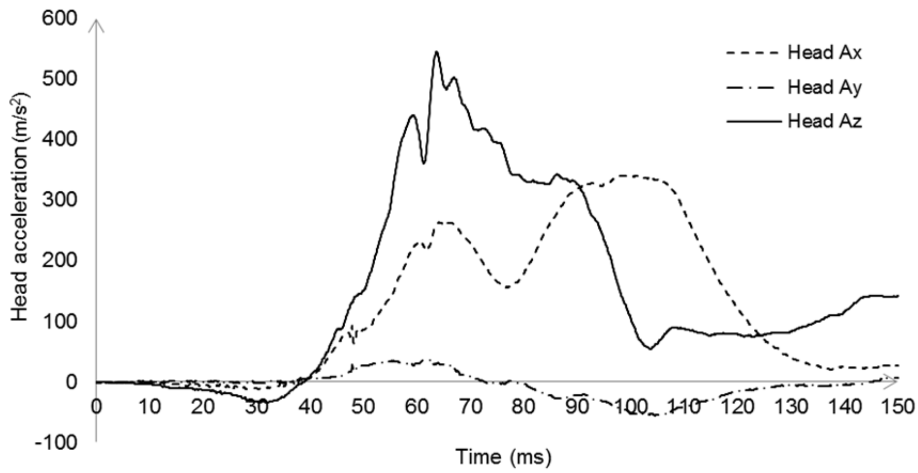
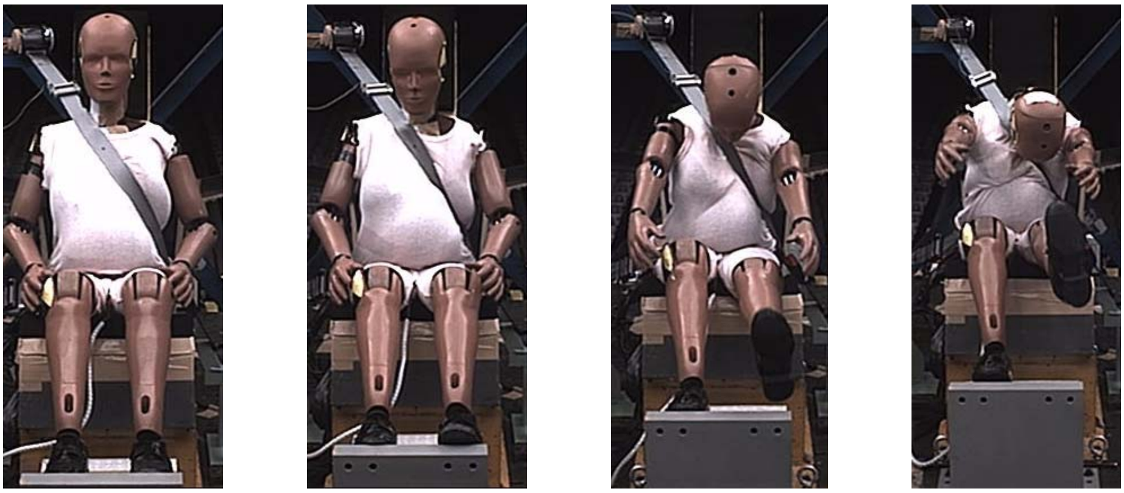


Fig. 5. Time course of head acceleration in each direction at an impact speed of 48 km/h.

Neck moments around each axis was measured. The time courses of the neck moment values around each axis are shown in Fig. 7. The maximum neck moment values around the X-axis (Mx), which suggest clockwise rotation around x-axis, were obtained at 81.8 ms after the initiation of low velocity impact (Mx=10.3 Nm) and at 71.1 ms after the initiation of high velocity impact (Mx=14.4 Nm).



(A) (B) (C) (D)

Fig. 6. Kinematic sequence showing the position of the dummy during a high velocity impact (A: 40 ms, B: 60 ms, C: 80 ms, D: 100 ms after impact initiation).

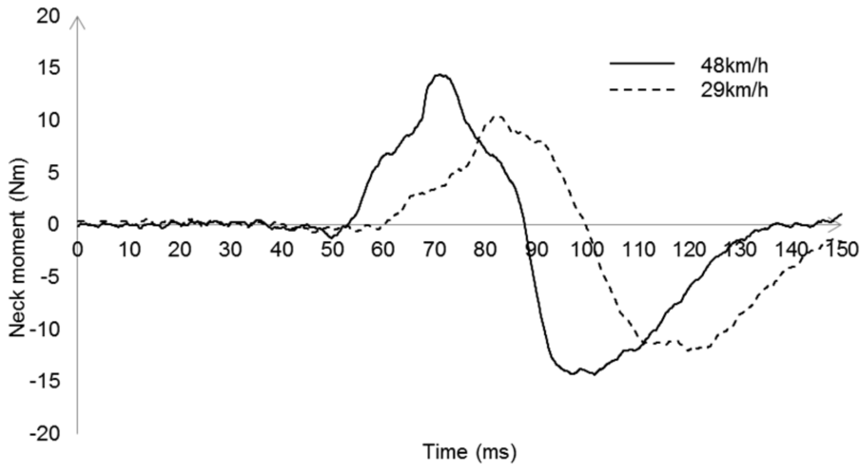


Fig. 7- A. Time course of neck moment values around the X-axis.

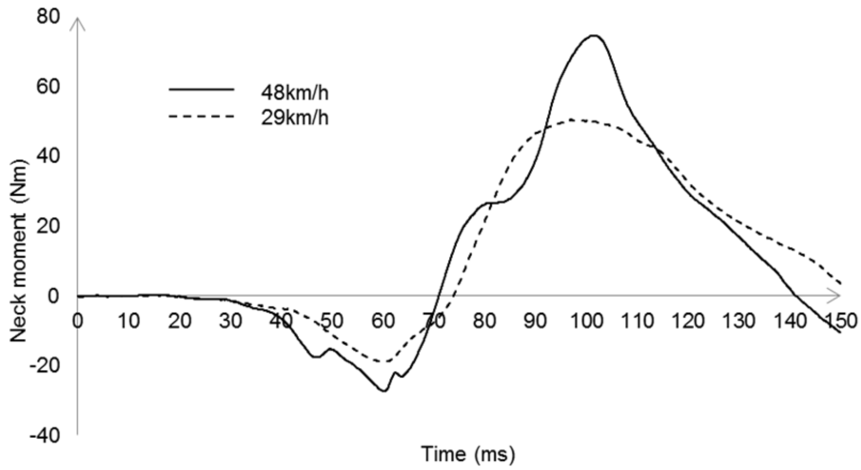


Fig. 7- B. Time course of neck moment values around the Y-axis.

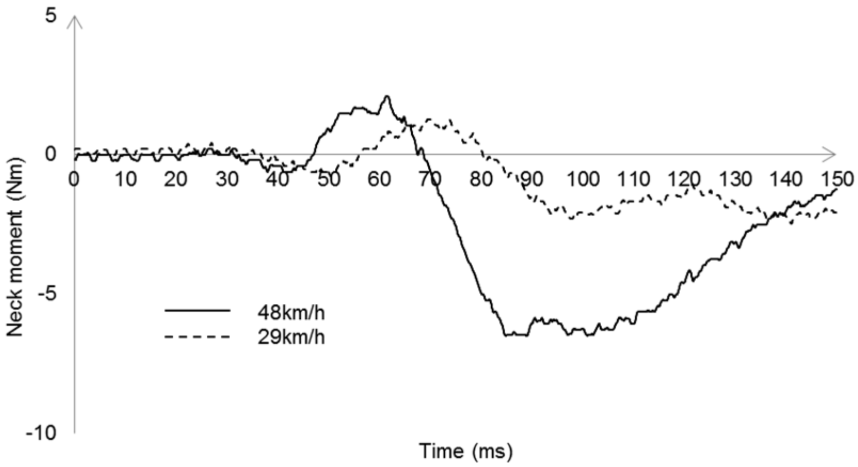


Fig. 7- C. Time course of neck moment values around the Z-axis.

3) Pressure applied to the neck

Where the shoulder belt made contact at the lower part of the right anterior region of the neck, a force of >12.8 MPa was measured during the low velocity impact. The high velocity impact resulted in high pressure over a markedly wider area of the neck.

IV. Discussion

Our results confirmed that some pregnant women in their third trimester experience contact between the shoulder belt and their neck when seated in the rear seat of a sedan. Because shoulder height adjusters are not legally required for rear seatbelts, most vehicles are not fitted with height adjusters in the rear. As a result, the seatbelt does not sit in the correct position for all rear-seat passengers. When the seatbelt is not correctly positioned relative to the chest, it does not provide effective protection in an impact scenario. The results of this study demonstrate that the rear seatbelt does not sit correctly on shorter (mean 152.3 cm) pregnant women who are similar in height to the 5^{th}%ile of adult females in America. The abdominal protrusion typical of late term of pregnancy causes the shoulder belt to deviate either to the right or left side to avoid crossing the abdomen. This allows the shoulder belt to easily make contact with the neck.

During full frontal collision sled tests, the shoulder belt compressed the neck and pressure greater than 12.8 MPa was applied to the neck even during low velocity impact. Our results show that, because the shoulder belt is anchored on the right side, passengers in the right rear seat may experience acceleration of the head from right to left in addition to neck flexion during impact. In addition, as the lower part of the neck was compressed by the seatbelt, a clockwise moment around the X-axis was also produced. This direct force on the neck may cause serious injuries to major vessels, such as the common carotid artery and vein, and nerves located in this region. Furthermore, the complex combination of head and neck movements including flexion, lateral deviation, and clockwise rotation around the x-axis, may cause neck sprain.

V. Conclusions

This is the first study to confirm that some smaller late-pregnant women experience contact of the shoulder belt with their neck, even if the seatbelt is used appropriately. Furthermore, the sled test reconstructions of frontal collisions of in a sedan vehicle showed that neck compression and head kinematics during impact may cause neck sprain. To adequately protect pregnant women, seatbelt systems for rear seats must be improved and a means of keeping the shoulder belt in the correct position for pregnant women should be developed.

VI. Acknowledgement

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VII. References

[1] Peden, M., Sminkey, L. (2004) World Health Organization dedicates World Health Day to road safety. *Injury Prevention*, **10**: p.67.

[2] Weiss, H.B., Songer T.J., Fabio A. (2001) Fetal deaths related maternal injury. *JAMA*, 286: p.1863-8.

[3] Morikawa, M., *et al*. (2016) Seatbelt use and seat preference among pregnant women in Sapporo, Japan in 2013. *Journal of Obstetrics and Gynaecology Research*, **42**: pp.810–15.

[4] Schiff M.A., Holt V.L. (2005) Pregnancy outcome following hospitalization for motor vehicle crashes in Washington State from 1989 to 2001. *American Journal of Epidemiology*, **161**: p.503-510.

[5] Klinich K.D., Flannagan C.A., Rupp.J.D., Sochor M., Schneider L.W., Pearlman M.D. (2008) Fetal outcome in motor-vehicle crashes: effects of crash characteristics and maternal restraint. *American Journal of Obstetrics Gynecology*, **198**: p.450.e1-450.e9.

[6] Wolf M.E., Alexander B. H., Rivara F.P., Hickok D.E., Maier R.V., Starzyk P.M. (1993) A retrospective cohort study of seat belt use and pregnancy outcome after a motor vehicle crash. *Journal of Trauma*, **34**: p.116-9.

[7] Michaelson, J., Forman, J., Lessley, D., Subit, D., Kent, R. Standard belt rear seat sled tests, HYBRID III 5th %ile female ATD, report covering tests: https://www-nrd.nhtsa.dot.gov/database/VSR/bio/TestDetail.aspx?LJC=10022&database=b&tstno=10022 [Accessed 27 March 2017].